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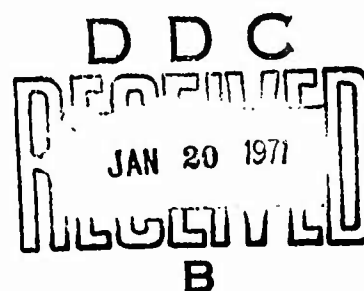
**INVESTIGATION OF ENGINE RIGGING,
AIRSPEED AND ROTOR RPM EFFECTS ON
STEADY STATE AUTOROTATIONAL PERFORMANCE**

FINAL REPORT

JOHN B. FITCH
LTC, ARM
US ARMY
PROJECT OFFICER/ENGINEER

JOHN J. SHAPLEY, JR.
PROJECT PILOT

DECEMBER 1970

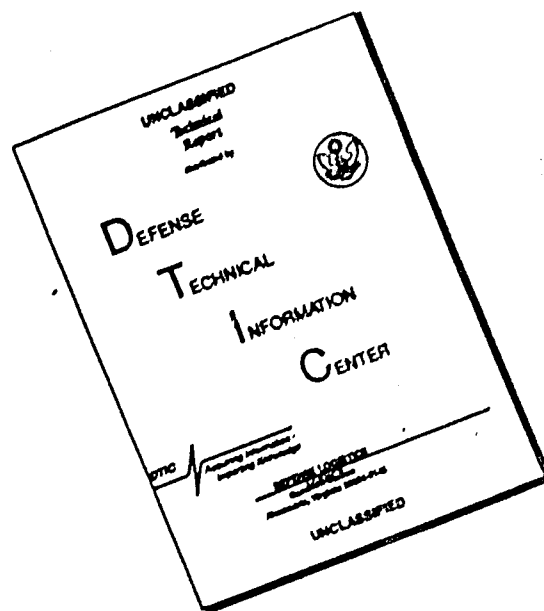


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**US ARMY AVIATION SYSTEMS TEST ACTIVITY
EDWARDS AIR FORCE BASE, CALIFORNIA 93523**

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ABSTRACT

A limited investigation was conducted by the US Army Aviation Systems Test Activity (USAASTA) at Edwards Air Force Base, California, to define the effects of various airspeeds, rotor speeds, engine rigging and gross weights on a UH-1C helicopter during autorotation. This investigation was prompted by a previous qualitative study of autorotational procedures (April 1968) and was requested by the Directorate of Rotary Wing Training, US Army Aviation School, Fort Rucker, Alabama. The latest investigation included 8 hours of productive flight testing between 6 and 14 October 1969, as well as a review of data obtained from earlier flight testing: the UH-1C Height-Velocity Study. Results of the investigation confirmed previous qualitative conclusions: that the use of low rotor speed to obtain maximum glide distance can be hazardous, especially at high gross weight conditions; and that current autorotation rate of descent information in operator's manuals is insufficient for the operator's use. The investigation further revealed that with a normal engine rigging, there is a measurable amount of engine output torque at low rotor speeds (310 rpm and below) during practice autorotations. This situation, encountered in a training environment, could produce a false sense of security in an individual faced with an actual emergency. Although the operational pilot cannot duplicate controlled test conditions, he should understand normal performance limits and the consequences of exceeding those limits. This report furnishes UH-1C autorotational data not currently available to the operator which should be incorporated into the appropriate manuals.

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INTRODUCTION

BACKGROUND

1. As a result of discussions with the Directorate of Rotary Wing Training, US Army Aviation School (USAAVNS), Fort Rucker, Alabama, a qualitative study (USAAVNTA Project No. 68-04) was conducted to evaluate the parameters which influence the autorotational descent performance of the UH-1 helicopter. Reference 1, appendix I, authorized direct contact with USAAVNS; therefore, US Army Aviation Systems Test Activity (USAASTA) personnel observed testing procedures and techniques at the school, and USAAVNS personnel observed testing at Edwards Air Force Base, California. Results of this study were published in final report form in April 1968 (ref 2).

2. Recommendations included in the final report of Project No. 68-04 listed the following:

a. "Maneuvering rate of descent information should be gathered during engineering flight tests and included in the operator's manual."

b. "Operators should exercise caution when using low rotor rpm techniques during the autorotational landing phase, especially under high gross weight operating conditions."

c. "Autorotation descent angle and rates versus airspeed information should be included in the operator's manual."

d. "Quantitative definition of the approach, landing and power recovery phases, should be accomplished."

3. A standard UH-1B helicopter with no test instrumentation was used for Project No. 68-04. Flight tests at aircraft gross weights of 6600 and 8800 pounds and mid center of gravity (cg) were performed at a steady state rate of descent in autorotation, holding constant airspeed and rotor speed. All readings were taken from standard instruments and time/distance measurements were calculated from the altimeter and a stop watch. Pitch angles, bank angles and sideslip angles were estimated by visual sensings of aircraft attitude and turn-and-bank indicator readings.

4. Subsequent to Project No. 68-04, during the UH-1C Height-Velocity Study (USAASTA Project No. 68-25), additional autorotational rate-of-descent data were obtained with a fully instrumented helicopter. Using one gross weight condition and three density altitudes, the rate of descent was determined for variations in airspeed, rotor speed and angle of sideslip. Analysis of the data is included in this report.

TEST OBJECTIVES

5. The objectives of this test were to quantify and establish relationships among the various parameters related to steady state autorotational descent. It was anticipated that an analysis and interpretation of the data would prove valuable to USAAVNS and also improve future engineering flight tests by USAASTA.

DESCRIPTION

6. The UH-1C is a utility helicopter having a single, semirigid, two-bladed main rotor and a semirigid, two-bladed antitorque tail rotor. It is powered by a Lycoming T53-L-11 free turbine engine with a maximum continuous power rating of 900 horsepower (hp) from 6400 to 6600 rpm. Normal operating gross weight varies from 6600 to 8500 pounds, with a maximum overload gross weight of 9500 pounds permitted. A skid-type landing gear is provided. The dual-control system consists of cyclic and collective sticks and antitorque directional pedals, all of which are of a hydraulically boosted, irreversible, positive mechanical type. A detailed description of the aircraft and associated systems is contained in reference 3, appendix 1.

SCOPE OF TEST

7. The study was limited to steady state autorotative descent performance of a UH-1C helicopter. Data from Project No. 68-25, which investigated the UH-1C's autorotational characteristics at a gross weight of 6700 pounds and density altitudes of 2000, 6000 and 11,000 feet, were also included in the analysis. Flight testing for this specific study was accomplished at a density altitude of 6000 feet using gross weights of 6700 and 8800 pounds. A mid cg location was maintained for all flights.

METHODS OF TEST

8. The steady state autorotational descent tests were performed by stabilizing at the desired density altitude. Applicable parameters were manually checked and recorded in flight using sensitive test instruments and a stop watch. These test instrumentation parameters are listed in appendix II. The data were subsequently verified or corrected through reference to photopanel films of flight test instrument readings. A listing of the specific test conditions is shown in table 1.

Table 1. Specific Test Conditions.

Project No.	Density Altitude (ft)	Gross Weight (lb)	True Airspeed (kt)	Rotor Speed (rpm)	Sideslip Angle (deg)
68-25	2,000	6,700	30 to 115	324	0
	6,000	6,700	30 to 135	324	0
	11,000	6,700	35 to 110	324	0
	6,000	6,700	59	290 to 340	0
	6,000	6,700	93	290 to 340	0
	6,000	6,700	59	324	45 left to 50 right
	6,000	6,700	93	324	25 left to 25 right
70-23	6,000	6,700	40 to 140	300	0
	6,000	6,700	66	250 to 330	0
	6,000	6,700	91	250 to 330	0
	6,000	8,800	45 to 105	300	0
	6,000	8,800	66	260 to 330	0
	6,000	8,800	91	260 to 330	0

CHRONOLOGY

9. The chronology of the testing is as follows:

Final report completed (Project No. 68-04)	April	1968
Flight testing accomplished (autorotations) (Project No. 68-25)	June	1968
Flight testing accomplished (Project No. 70-23)	October	1969
Preliminary report submitted	December	1969

RESULTS AND DISCUSSION

GENERAL

10. The UH-1C operator's manual provides a minimum amount of information concerning autorotational performance. Recommended procedures following engine failure during flight include the following:

- a. "Collective pitch-reduce as required to maintain rotor rpm within limits."
- b. "Establish autorotational glide with airspeed 60 knots or as required to make forced landing area."

Subsequent paragraphs entitled "Minimum Rate of Descent" and "Maximum Glide" read as follows:

- c. "The power-off minimum rate of descent is obtained by maintaining an indicated airspeed of approximately 53 knots and rotor rpm of approximately 295."
- d. "Maximum gliding distance is obtained by an indicated airspeed of 84 knots and rotor rpm of 295."

11. No discussion of the effects of various gross weights, airspeeds, rotor speeds, or density altitude on autorotational performance is found in current operator's manuals. The only mention of these items in the UH-1C manual (ref 3, app I) is found in notes to a figure displaying maximum power-off glide distance as a function of pressure altitude. The notes state that the conditions for the plot are an average gross weight of 8500 pounds and a rotor rpm of 324. The following additional statements are also presented with this figure:

- "(1) Autorotational descent performance is a function of airspeed and essentially unaffected by density altitude and gross weight."
- "(2) The speed for best glide distance is 105 knots IAS."
- "(3) The speed for minimum rate of descent is 59 knots IAS."

To the average pilot, notes (2) and (3) above would appear to conflict with the previously quoted information.

12. Current published autorotational practice procedures (for USAAVNS) specify an entry airspeed of 80 knots followed by cyclic adjustment to maintain 70 knots indicated airspeed (KIAS) until the deceleration phase. Rotor rpm is to be maintained between 294 and 324 with collective adjusted above full-down only if rpm exceeds the mid-green range (310 rpm).

13. Considering the range of autorotational airspeed and rotor speeds presented in the operator's manual, it appears that the published USAAVNS procedures (ref 5, app I) represent an acceptable compromise for normal practice. However, many unanswered questions remain as to the exact relationships among the pertinent variables. Individual speculation and experimentation by instructor pilots can result in false beliefs about optimum airspeed and/or rotor speed combinations.

14. This report quantifies the effects of significant parameters involved in autorotative descent, thereby establishing a meaningful range of values. It verifies many of the conclusions of Project No. 68-04 by means of flight test data obtained from accurate instruments in a controlled test environment. It does not, however, present a complete method for optimum performance of autorotations. An optimum method involves considerations of entry, final approach and touchdown, in addition to steady state descent. Such a method must also account for such diverse parameters as height above the ground, relative position, and nature of the landing site, wind velocity, operator level of proficiency, and similar factors which vary with each situation.

15. The average pilot, having neither precise instrumentation in the aircraft nor a controlled test environment, is not likely to match flight test optimum rates of descent. The principal value of this report is that it provides the operator with a recommended performance envelope and predicts what is to be expected at the extremes of that envelope. The US Army Aviation School can benefit from this report by using it as a basis upon which to develop optimum autorotation techniques. From an engineering flight test point of view, it can be used as an example of the type of information which should be generated for use in operator's manuals.

CONSIDERATIONS

16. The qualitative aspects of autorotation are well discussed in the final report of Project No. 68-04 (ref 2, app I) and are not included in this report. However, that report should be read in conjunction with this one, since the data presented herein serve to verify the results and conclusions of the previous study. It will be noted that values obtained for minimum rate of descent are different in the two reports, those of the more recent test being higher. This is due chiefly to the fact that the earlier tests were conducted without benefit of precise instrumentation. Moreover, it was discovered in subsequent testing that a measurable amount of torque is delivered to the rotor system when rotor rpm is in the mid-green range (310 rpm) or below and the throttle is set at the engine flight idle position. In both studies, however, trends are identical. Rate of descent was found to be relatively insensitive to airspeed or gross weight when operating within 10 knots of the minimum rate-of-descent speed. In contrast, as high or low airspeed extremes were approached, rates built up rapidly. The rate of descent became significantly higher at maximum glide distance airspeeds; while at airspeeds from 15 to 20 knots less than that for minimum descent, the rate of descent became extremely high. Similarly, higher rates of descent were encountered with increasing sideslip angle. During both studies, it was noted that density altitude (at pressure

altitudes below 11,000 feet) has little effect on rate of descent, although obviously it is highly significant in the deceleration and landing phases of an autorotation. Bank angle effects were investigated during the first study only where it resulted in higher rates of descent at all airspeeds. A detailed explanation of the effects of various parameters is found in paragraphs 17 through 25.

AIRSPEED EFFECT

17. Rate-of-descent variation with airspeed is depicted in figures 1, 2 and 3, appendix III. In these tests, rotor rpm, gross weight and density altitude were held constant in straight, steady state autorotation while airspeed was varied in 10-knot increments. The curves show a pronounced "bucket" (minimum slope of the curve) between 50 and 80 knots true airspeed (KTAS). Below 50 knots and above 80 knots, rate of descent increases rapidly with minor changes in airspeed, although the variation is less pronounced at the higher airspeeds. Minimum rate of descent, in all instances, was achieved in the vicinity of 60 KTAS, varying less than 10 percent from the minimum value throughout the 30-knot interval from 50 to 80 KTAS. Below 50 knots, the helicopter descent path approaches the vertical, while aircraft attitude moves toward that required for hover. True airspeed, being a measure of flight path velocity, approaches true vertical speed in this situation. To provide a more realistic picture of translation with respect to the ground, true airspeed rate-of-descent curves are faired to corrected horizontal-speed values at points below 40 KTAS. It should be noted that, in this area of the flight envelope, pitch angle is virtually useless as an indicator of airspeed, the helicopter being in a nearly level-flight attitude.

18. The hazards associated with attempting to shorten or stretch an autorotational glide by means of airspeed are readily apparent on the airspeed curves. The situation becomes especially critical at airspeeds below 40 KTAS because of the large low-speed position error inherent to helicopter pitot-static systems. Vertical speeds up to 4000 feet per minute (fpm) may result from a decrease of a few knots in airspeed on the low-speed portion of the curve. Although not as hazardous a situation, the use of best glide speeds (from 90 to 100 KTAS) will result in vertical speeds at least 300 fpm higher than the minimum rate of descent. Above 100 KTAS, small increases in airspeed will generate much higher rates of descent.

19. Gross weight has a minimal effect on the airspeed/rate-of-descent curves. An increase in gross weight decreases the slope of the high-speed portion of the curve, thereby increasing the best glide speed. Test results show a best glide speed of 90 KTAS at a 6700-pound gross weight (300 rpm, 6000-foot density altitude). Under the same conditions, except for a weight increase to 8800 pounds, the best glide speed was 102 KTAS (figs. 2 and 3, app III).

ROTOR SPEED EFFECT

20. Rate-of-descent variation with rotor speed is depicted in figures 4, 5 and 6, appendix III. Data for these plots were obtained by the same method used for

the airspeed curves, except that rotor speed was varied in 10-rpm increments while airspeed was held constant. The data shown in figure 4 were compiled during testing for Project No. 68-25. In these tests, it was determined that as much as 5 pounds per square inch (psi) of indicated torque were being delivered to the rotor system at rotor rpm settings of 310 or less. Subsequent testing confirmed this situation to be the normal for a properly rigged UH-1C in autorotation using flight idle power. To provide a realistic performance appraisal of an actual engine-out condition, data for figures 5 and 6 were obtained using a gas producer (N_1) setting of 50-percent power-available at flight idle, in contrast to the normal 60-percent N_1 setting for the UH-1C. This lower setting resulted in a good "needle-split" down to 250 rpm rotor speed, with no measurable torque being observed. A comparison of figures 4 and 5 shows that the modified N_1 setting resulted in an increase in the rate of descent on the order of 100 to 150 fpm at the lower rotor rpm values. During steady state descent, this is of little importance. However, when near the ground and at heavy weight with low rotor speeds, the power input can result in an unrealistic impression of the autorotational performance.

21. Figures 5 and 6, appendix III, indicate that reducing rotor speed fails to produce lower autorotational rates of descent at high gross weight. For the low gross weight condition (6700 pounds) at an airspeed (66 KTAS) corresponding to that for minimum rate of descent at a constant rotor speed, the observed rate of descent decreased to a minimum value of approximately 270 rpm and remained nearly constant for rotor speeds as low as 250 rpm (UH-1C manual minimum allowable rotor speed, normal operation: 294 rpm). At the same light gross weight with an airspeed (91 KTAS) corresponding to the best glide speed, reducing the rotor speed from 294 rpm to obtain a minimum descent rate at 275 rpm resulted in an improvement in vertical speed of only 50 fpm. Below 270 rpm, a rapid increase in rate of descent was experienced. At the heavier gross weight condition (8800 pounds), a rapid build-up in rate of descent was noted at rotor speeds below 300 rpm for both airspeeds tested (fig. 6).

22. Despite the apparent gain in rate-of-descent performance at rotor speeds below 294 rpm for the condition of light gross weight, operation in this region is not recommended for several reasons:

- a. Rotor speed lost to obtain a small decrease in rate of descent must be regained prior to initiation of the deceleration phase of autorotation.
- b. Even with sensitive flight test instruments, it is difficult to maintain steady state descent because minor changes in airspeed produce significantly higher vertical speeds.
- c. It is probable that operation at low rotor speeds may produce undesirable stress on rotor system components.
- d. Practice autorotations at flight idle power, low gross weight and low rotor speed do not represent the conditions normally encountered in an engine-out emergency.

SIDESLIP EFFECT

23. Figures 7 and 8, appendix III, depict rate-of-descent variations with sideslip angle at a gross weight of 6700 pounds and a rotor speed of 324 rpm. For any amount of sideslip, there is a significant increase in rate of descent. The effect is further increased by higher airspeeds. Although not verified by test, it is probable that the effect would also be aggravated at airspeeds of less than 50 knots. As observed during the testing on Project No. 68-04, sideslip in conjunction with a banked turn can produce high rates of descent.

24. In the standard helicopter, there is no way to measure sideslip other than by means of visual reference to ball displacement in the turn-and-bank indicator. The relative inaccuracy of this instrument in its use as a sideslip indicator is depicted by figures 9 and 10, appendix III. For these tests, a UH-1B helicopter equipped with a boom-mounted sideslip indicator (in addition to the standard turn-and-bank instrument) was flown at varying airspeeds and sideslip angles. The pilot's readout of ball displacement was recorded for corresponding sideslip angles at 30, 60 and 90 KIAS in climbs, descents, and level flight. The results show that ball displacement is a function of airspeed and power, as well as sideslip angle. At slow speeds or low power settings, an appreciable amount of sideslip may be present with little or no resultant ball displacement. This is dependent upon the static directional stability characteristics and will vary with different types of aircraft. It is apparent that the pilot's ability to recognize sideslip in an autorotation at low airspeed is relatively poor.

HORIZONTAL GLIDE DISTANCE

25. Figures 11, 12, 13 and 14, appendix III, are plots of horizontal glide-distance variation with airspeed and rotor speed. These plots were calculated for a vertical descent of 1500 feet, zero wind, using the same flight test data shown in figures 1 through 6. It should be noted that decreasing rotor speed below mid-green (310 rpm) produces only a modest increase in glide distance at high gross weight. Airspeeds above the speed for minimum rate of descent produce a significant increase in glide distance up to about 80 knots, but only a gradual increase from that point to the best glide speeds. At airspeeds below 50 knots, the curve for figure 11 was corrected to depict horizontal speed rather than true airspeed for the same reason noted in paragraph 17.

26. The horizontal glide plots make it evident that airspeed is the governing factor in obtaining the best glide distance. Unless the aircraft is at a considerable height above the ground, it would be unwise to choose the best glide airspeed because of the high rates of descent shown in figures 1 through 3, appendix III. For a light gross weight condition, the maximum glide distance may be obtained with a combination of low rotor speed (280 rpm) and high airspeed (91 KTAS); however, for other than fully instrumented test flights, these values are not recommended because of reasons given in paragraph 22. In summary, it appears that 70 knots is a good compromise airspeed for maximum distance and minimum rate of descent, keeping rotor speed in the mid-green (310 rpm).

CONCLUSIONS

GENERAL

27. The following general conclusions were obtained from this investigation:

- a. Autorotational performance data in the UH-1C operator's manual is misleading (paras 10, 11, 17 and 20).
- b. Published UH-1 autorotational practice procedures of USAAVNS are essentially correct; however, they are incomplete (paras 12, 13, 17 and 20).
- c. The use of a low rotor rpm technique to achieve reduced rates of descent or longer glide distances in autorotation is valid only under a limited set of conditions and should be avoided by the average pilot (para 22).
- d. Airspeed is the most important factor that influences horizontal glide distance in autorotation (para 26).
- e. Density altitude has a negligible effect on the rate of descent in steady state autorotation at pressure altitudes below 11,000 feet (paras 16 and 17).
- f. Sideslip angle, bank angle and nonsteady state conditions will increase the rate of descent in autorotation (paras 22, 23 and 24).
- g. Maximum glide distance airspeeds should be avoided unless adequate height is available to compensate for the resultant high rates of descent (para 18).
- h. In practice autorotations in the UH-1C, rates of descent at a mid-green (310 rpm or lower) rotor speed setting are not representative of actual emergency situations because a measurable amount of torque is delivered to the rotor system at the engine flight idle position (paras 20 and 22).

SPECIFIC

28. The following specific conclusions were obtained from this investigation:

- a. The normal range of airspeeds for UH-1C steady state autorotations should be 50 to 80 KTAS (para 17).
- b. The recommended airspeed/rotor speed combination for UH-1C autorotations is 70 KTAS, mid-green (310 rpm) range (para 26).
- c. With rotor speed in the normal operating range (294 to 324 rpm) and airspeeds between 50 and 80 KTAS, coordinated steady state autorotational rates of descent in the UH-1C do not exceed 2000 fpm, regardless of density altitude or gross weight (mid cg loading) (paras 17 and 20).

d. Airspeed for minimum rate of descent in coordinated steady state autorotation in the UH-1C is 59 to 63 KTAS, regardless of rotor speed, density altitude or gross weight (mid cg loading) (para 17).

e. Airspeed for maximum glide distance in coordinated steady state autorotation in the UH-1C varies from 87 KTAS at low gross weight (6700 pounds) to 102 KTAS at high gross weight (8800 pounds), regardless of density altitude (para 25).

f. Pitch angle cannot be used to estimate airspeed in autorotation when the true airspeed falls below 50 knots (para 17).

g. The pilot's ability to recognize sideslip in low airspeed autorotations is relatively poor (para 24).

RECOMMENDATIONS

29. It is recommended that:

- a. Autorotational performance data in the UH-1C operator's manual be amended to reflect the results of this investigation.
- b. The US Army Aviation School review the results of this investigation to determine if autorotational training procedures require revision.
- c. The US Army Board for Aviation Accident Research compare the results of this investigation with autorotational accident data to determine if dissemination of the information might help prevent future accidents.
- d. An investigation of a similar nature be performed in conjunction with engineering flight tests on all new and improved helicopters.
- e. The results of this investigation be incorporated into all new or revised editions of operator's manuals.

APPENDIX I. REFERENCES

1. Letter, Test Directive, AMSAV-ER, USAAVSCOM, 13 Dec 1967, subject: Request for Special Study, Autorotational Procedures.
2. Final Report, US Army Aviation Test Activity (USAAVNTA), Project No. 68-04, *Special Study of Autorotational Procedures*, February 1968.
3. Operator's Manual, TM 55-1520-220-10, *Army Model UH-1C Helicopter*, November 1968.
4. Letter, Test Directive, AMSAV-R-F, USAAVSCOM, 20 June 1970, subject: USAAVSCOM Test Directive No. 70-23, Investigation of UH-1B/C Autorotational Performance.
5. Manual, Department of Rotary Wing Training, USAAVNS, Fort Rucker, Alabama, *Standardization of Helicopter Maneuvers, UH-1A, B, C, D, H*, Revised 1969.

APPENDIX II. TEST INSTRUMENTATION

Sensitive instruments were installed and maintained by USAASTA, the following were used to record parameters:

PILOT PANEL (Visual)

Boom system airspeed
Boom system altimeter
Rotor speed
Angle of sideslip
Angle of attack
Clock
Fuel quantity

ENGINEER PANEL (Visual)

Ship system airspeed
Ship system altimeter
Fuel totalizer
Torque pressure
Free air temperature
Photograph counter number
Stopwatch
Event recorder

PHOTOPANEL

Ship system airspeed
Boom system airspeed
Ship system altimeter
Boom system altimeter
Rotor speed
Free air temperature
Clock
Elapsed time indicator
Fuel totalizer
Photograph counter number
Event marker

APPENDIX III. TEST DATA

FIGURE 1
 RATE OF DESCENT VARIATION WITH AIRSPEED
 UH-1C USA S/N 63-8684
 AVG GROSS WT = 6700 LBS
 ROTOR SPEED = 324 RPM

SYM	AVG DENSITY ALTITUDE FT
△	2000
○	6000
□	11000

NOTE: SOLID SYMBOLS
 OBTAINED FROM CURVES
 ON FIGURE 4
 AT 300 RPM.

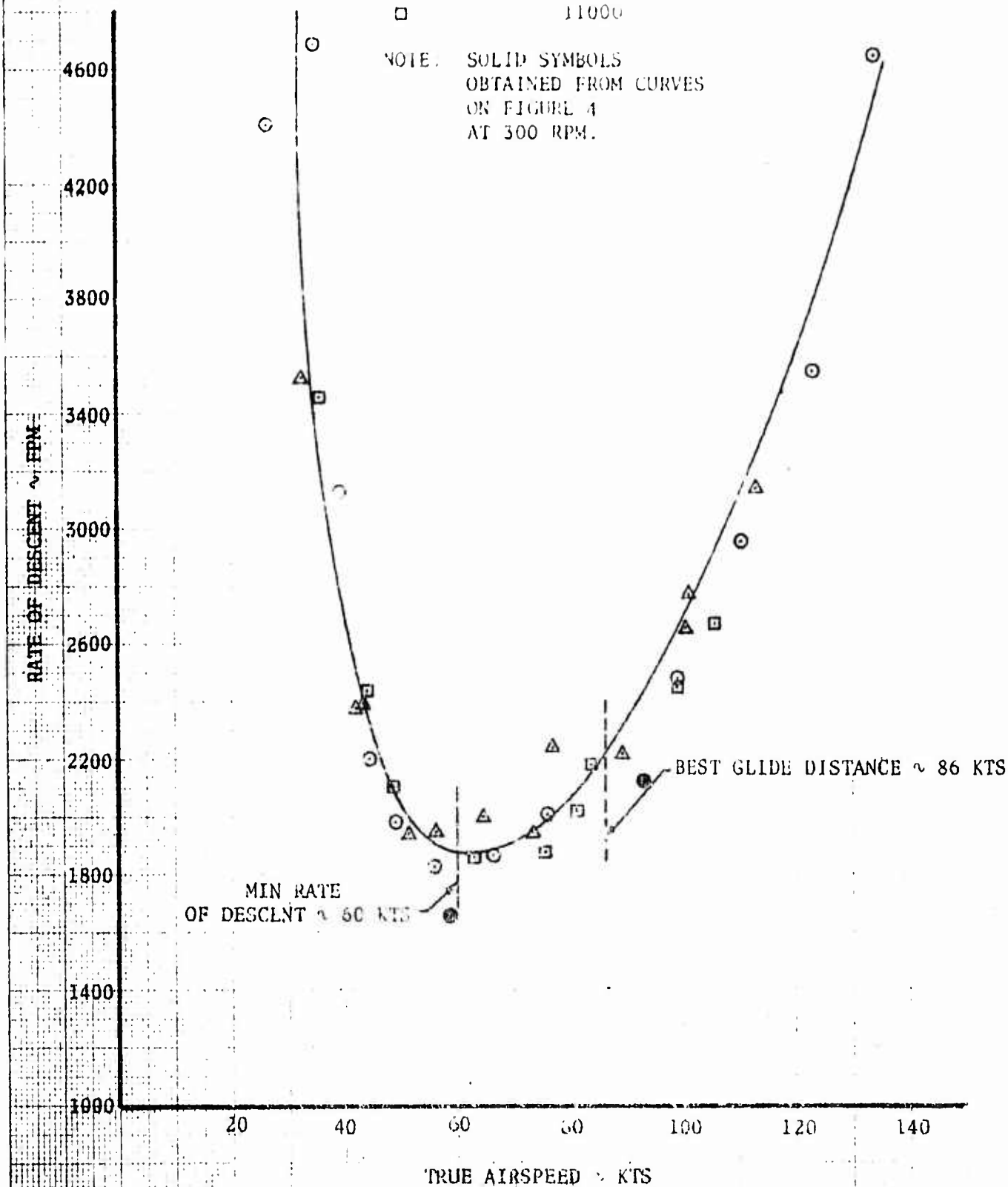


FIGURE 2
RATE OF DESCENT VARIATION WITH AIRSPEED
UH-1C USA S/N 63-8684

AVG GROSS WT = 6700 LBS
AVG DENSITY ALT = 6000 FT
ROTOR SPEED = 300 RPM

SYM

- ~ V_T BOOM
- ~ V_T HORIZ.
- ~ FROM FIG 5 @ 320 RPM
- ~ FROM FIG 5 @ 260 RPM

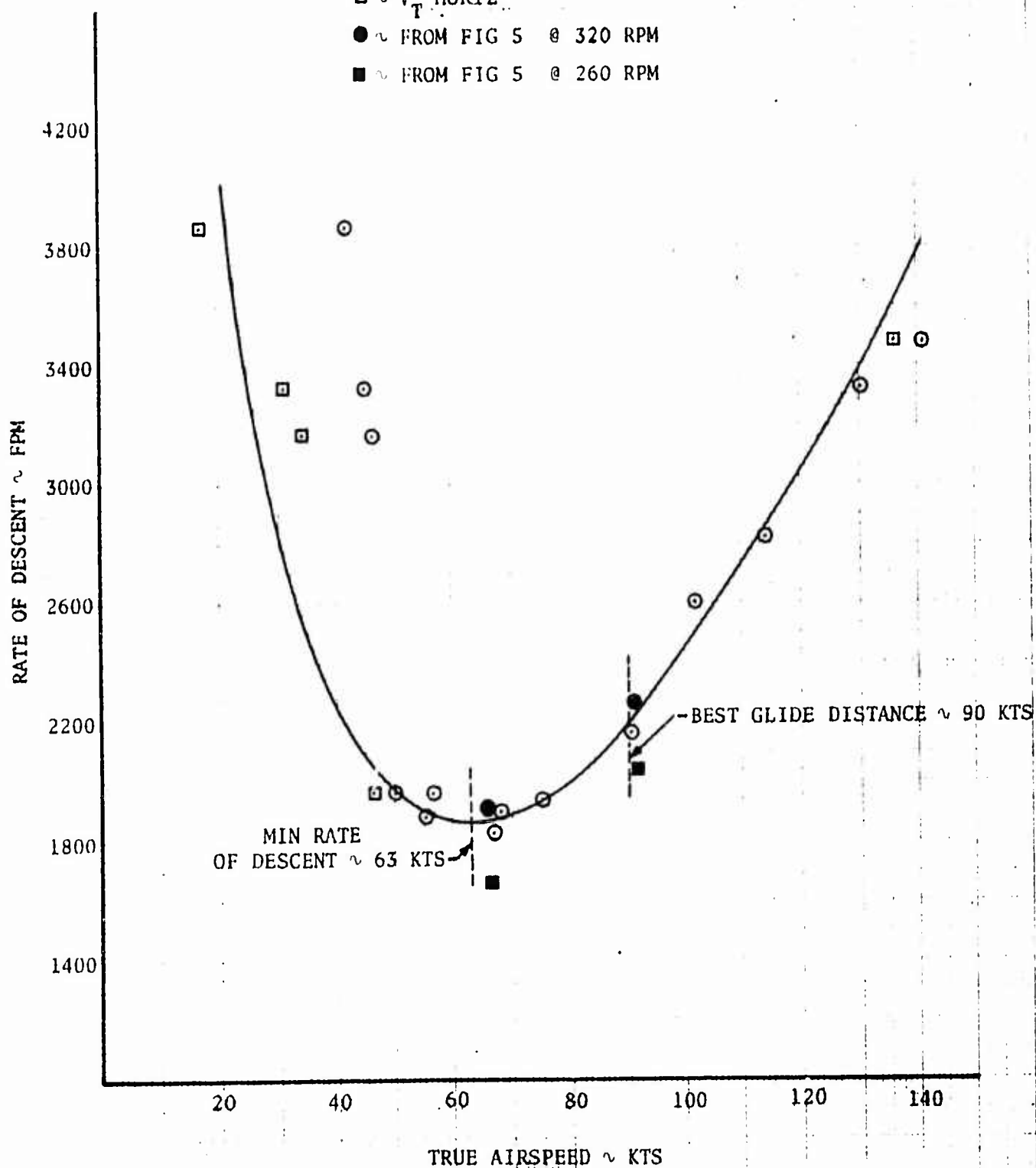


FIGURE 3
 RATE OF DESCENT VARIATION WITH AIRSPEED
 UH-1C USA S/N 63-8684
 AVG GROSS WT = 8800 LBS
 AVG DENSITY ALT = 6000 FT
 ROTOR SPEED = 300 RPM

SYM

- ~ V_T BOOM
- ~ V_T HORIZ
- ~ FROM FIG 6 @ 320 RPM
- ~ FROM FIG 6 @ 260 RPM

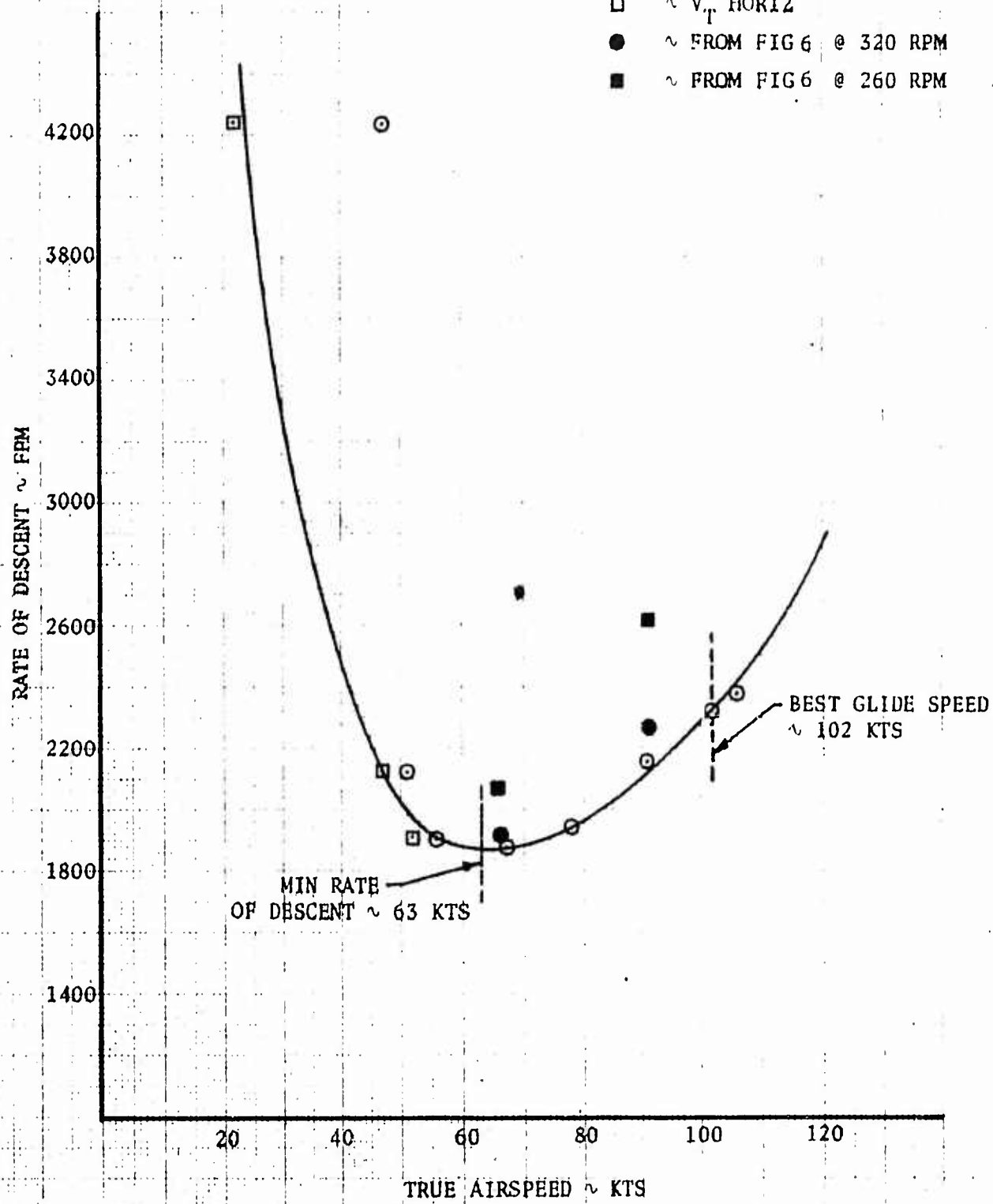


FIGURE 4
RATE OF DESCENT VARIATION WITH ROTOR SPEED
UH-1C USA S/N 63-8684

AVG GROSS WT = 6700 LBS
AVG DENSITY ALT = 6000 FT

SYM TRUE AIRSPEED ~ KTS

○ 59

△ 93

NOTES:

1. SOLID SYMBOLS OBTAINED FROM CURVES ON FIGURE 1

2. * DENOTES QUESTIONABLE DATA (ENGINE POWER NOT ZERO)

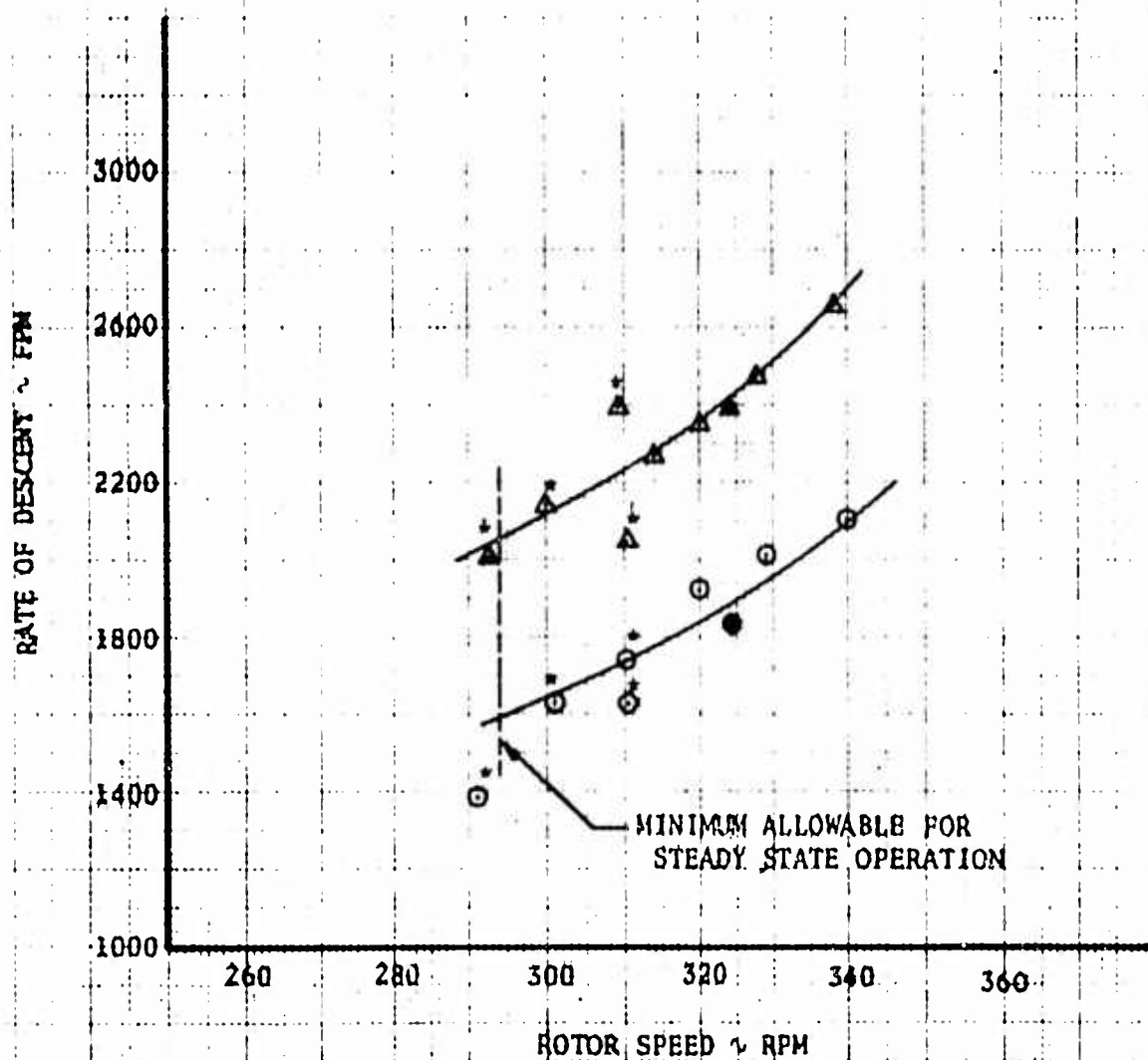


FIGURE 5
 RATE OF DESCENT VARIATION WITH ROTOR SPEED
 UH-1C USA S/N 63-8684
 AVG GROSS WT = 6700 LBS
 AVG DENSITY ALT = 6000 FT

SYM	TRUE AIRSPEED - KTS
○	66
□	91
●	From Fig 2 @ 66
■	From Fig 2 @ 91

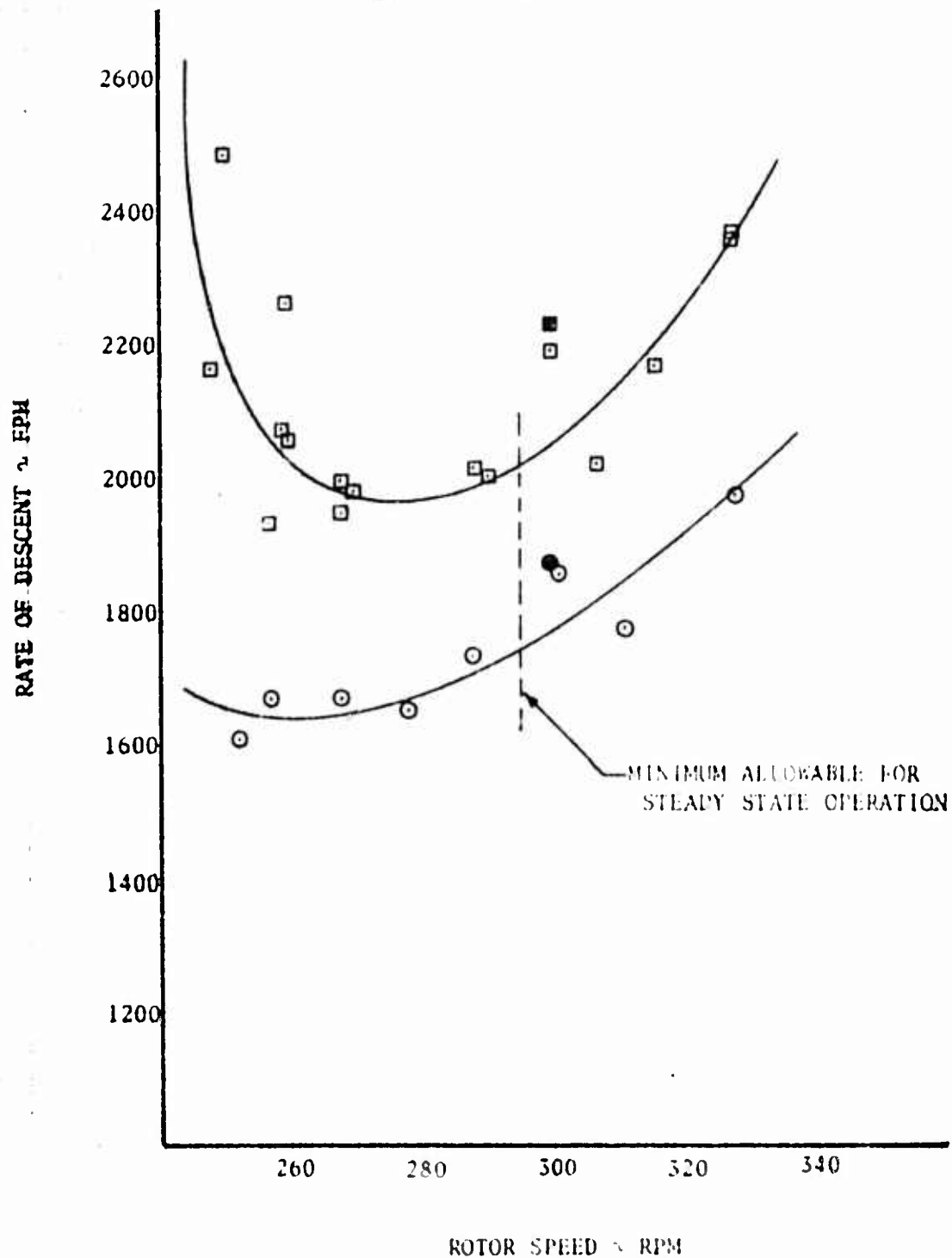


FIGURE 6
 RATE OF DESCENT VARIATION WITH ROTOR SPEED
 UH-1C USA S/N 63-8684

AVG GROSS WT = 8800 LBS
 AVG DENSITY ALT = 6000 FT

SYM TRUE AIRSPEED ~ KTS
 ○ 66
 □ 91
 ● From Fig 3 @ 66
 ■ From Fig 3 @ 91

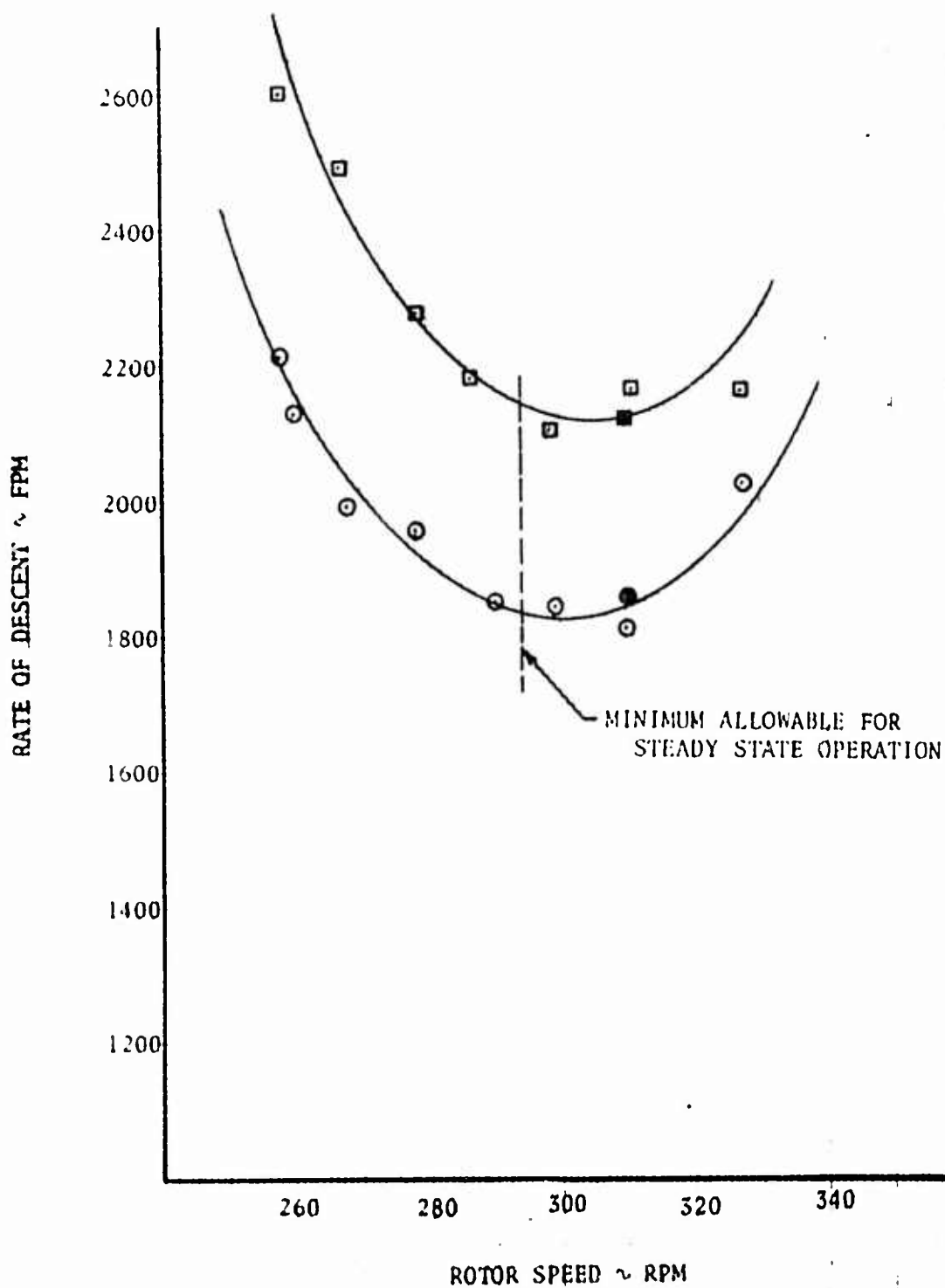


FIGURE 7
 RATE OF DESCENT VARIATION WITH SIDESLIP ANGLE
 UH-1C USA S/N 63-8684

AVG GROSS WT = 6700 LBS
 AVG DENSITY ALT = 6000 FT
 ROTR SPEED = 324 RPM
 SYM TRUE AIRSPEED ~ KTS

○ 59
 △ 93

NOTE: SOLID SYMBOLS
 OBTAINED FROM CURVE
 ON FIGURE 1

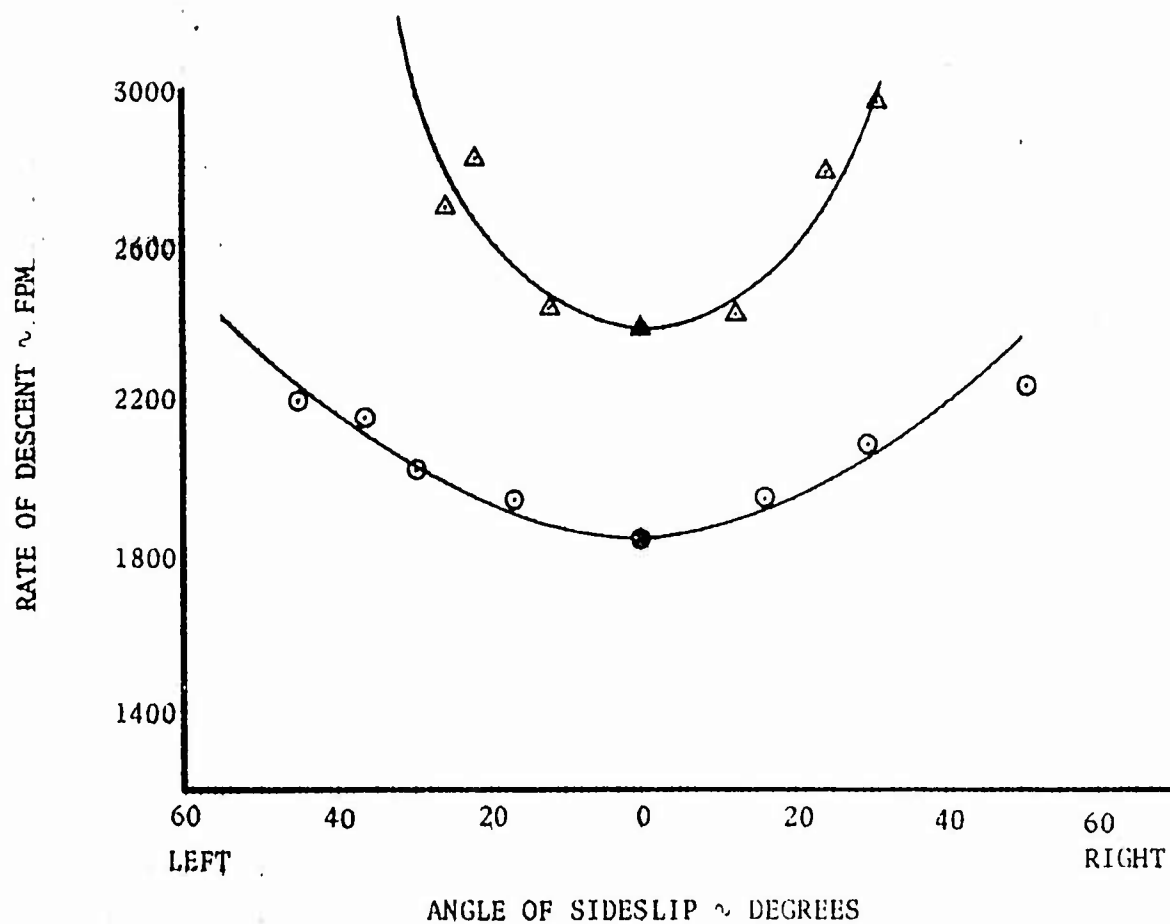


FIGURE 8
 RATE OF DESCENT VARIATION WITH SIDESLIP ANGLE
 UH-1C USA S/N 63-8684

AVG GROSS WT = 6700 LBS
 AVG DENSITY ALT = 6000 FT
 ROTOR SPEED = 324 RPM

- NOTES: 1. CURVES BASED ON FIGURES 1 AND 7
 2. RATE OF DESCENT INCREASE IS AVERAGE OF INCREASE FOR LEFT AND RIGHT SIDESLIP ANGLES.

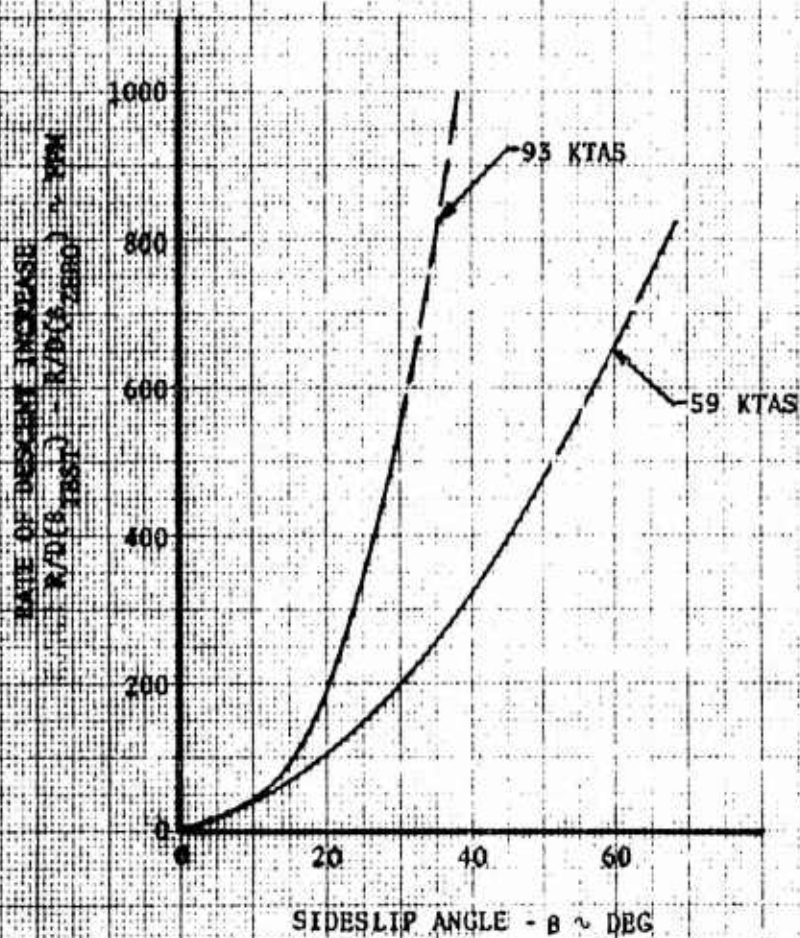


FIGURE 9
COMPARISON OF ACTUAL AND INDICATED SIDESLIP ANGLE
UH-1C
USA S/N 63-8684

AVG INDICATED AIRSPEED = 60 KTS

AVG GROSS WT = 6700 LB

SYM FLIGHT REGIME

○ CLIMB
□ DESCENT
△ LEVEL FLT

NOTE:

1. RECORDED FROM THE PILOT'S STATION.
2. * DENOTES CLIMB AND DESCENT RATES GREATER THAN 500 FPM.

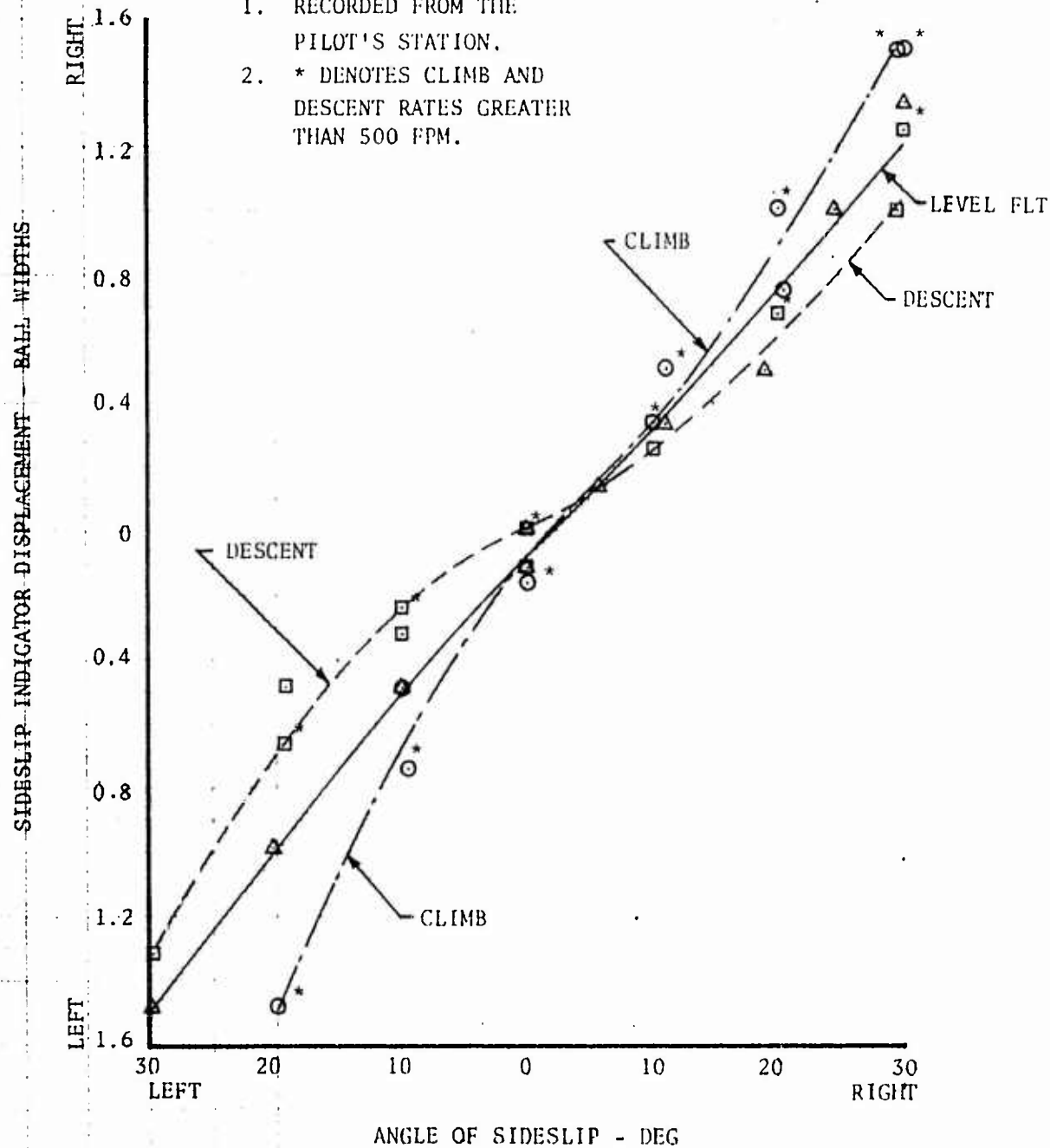


FIGURE 10
COMPARISON OF ACTUAL AND INDICATED SIDESLIP ANGLE
UH-1C USA S/N 63-8684

AVG GROSS WT = 6700 LBS
AVG DENSITY ALT = 5000 FT

SYM	AVG INDICATED AIRSPEED ~ KTS
○	30
□	60
△	90

- NOTES:
1. RECORDED FROM THE PILOT'S STATION.
2. LEVEL FLIGHT.

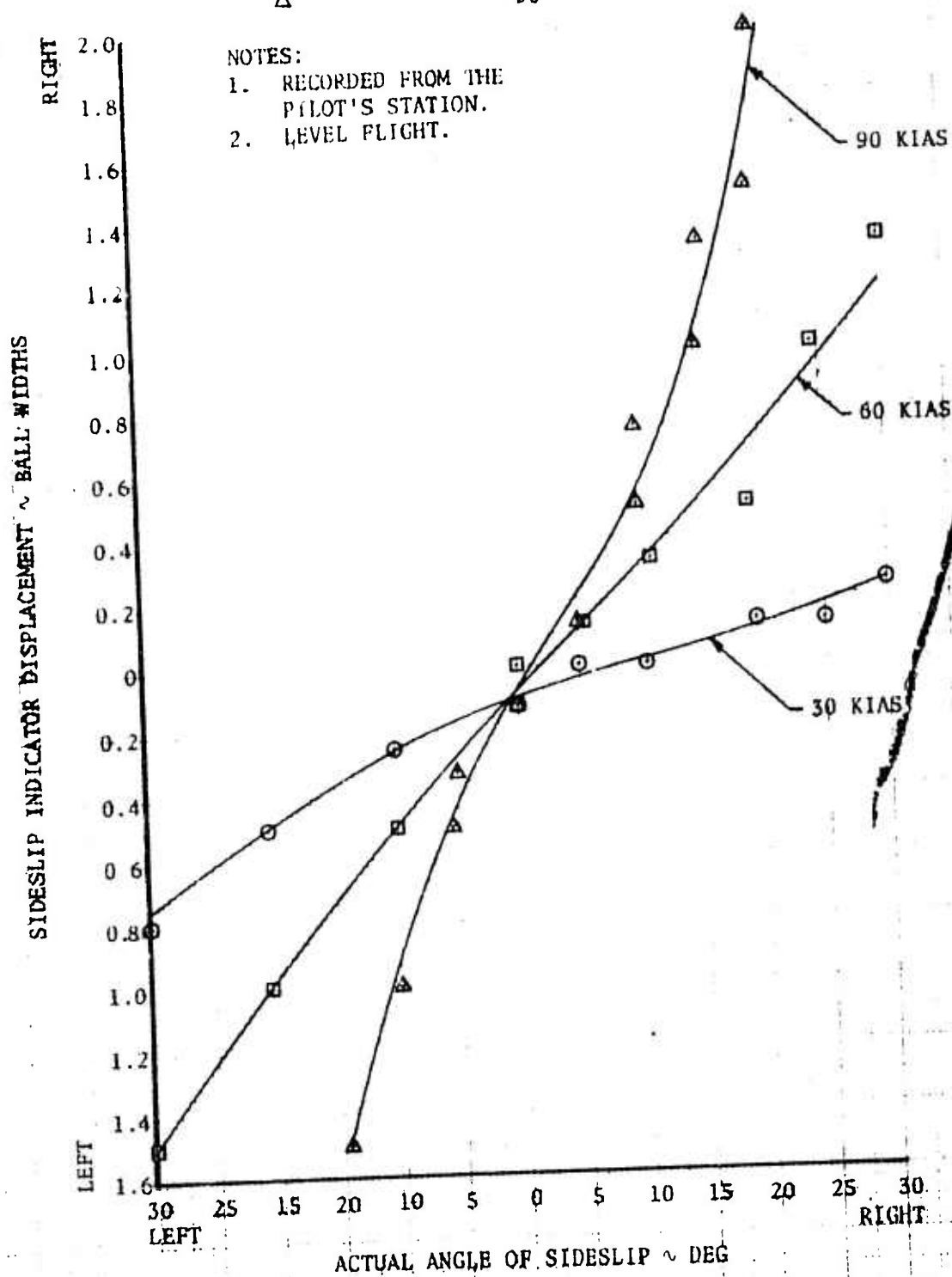


FIGURE 11
HORIZONTAL GLIDE DISTANCE VARIATION WITH AIRSPEED
UH-1C USA S/N 63-8684

AVG DENSITY ALT = 6000 FT
ROTOR SPEED = 300 RPM
VERTICAL DESCENT = 1500 FT

SYM	GROSS WEIGHT ~ LB
○	6700
△	6700 (V_{Horiz})
□	8800
▽	8800 (V_{Horiz})

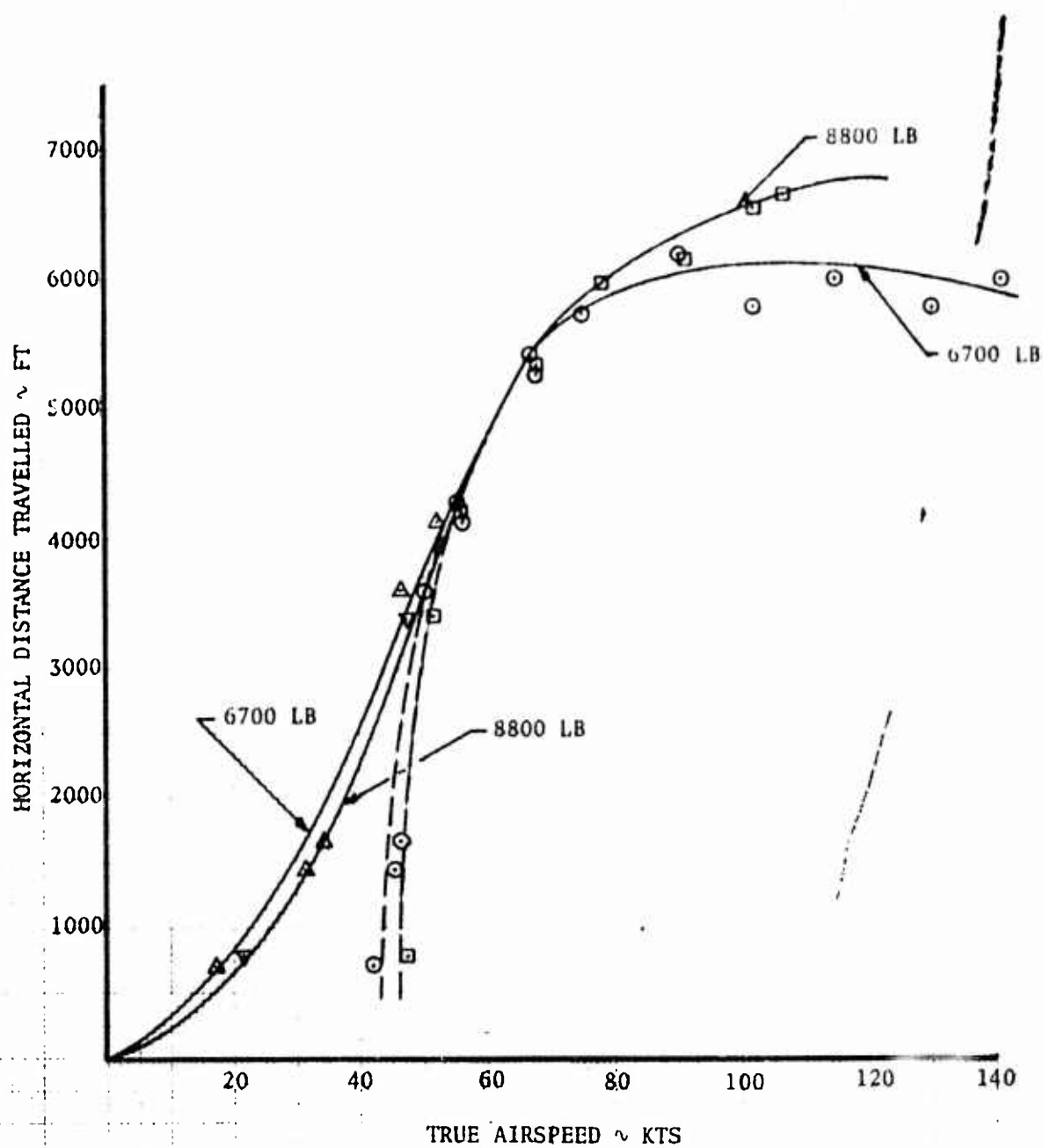


FIGURE 12
HORIZONTAL GLIDE DISTANCE VARIATION WITH AIRSPEED
UH-1C USA S/N 63-8684

AVG DENSITY ALT = 6000 FT
ROTOR SPEED = 300 RPM
VERTICAL DESCENT = 1500 FT

SYM	GROSS WEIGHT ~ LB
○	6700
□	8800

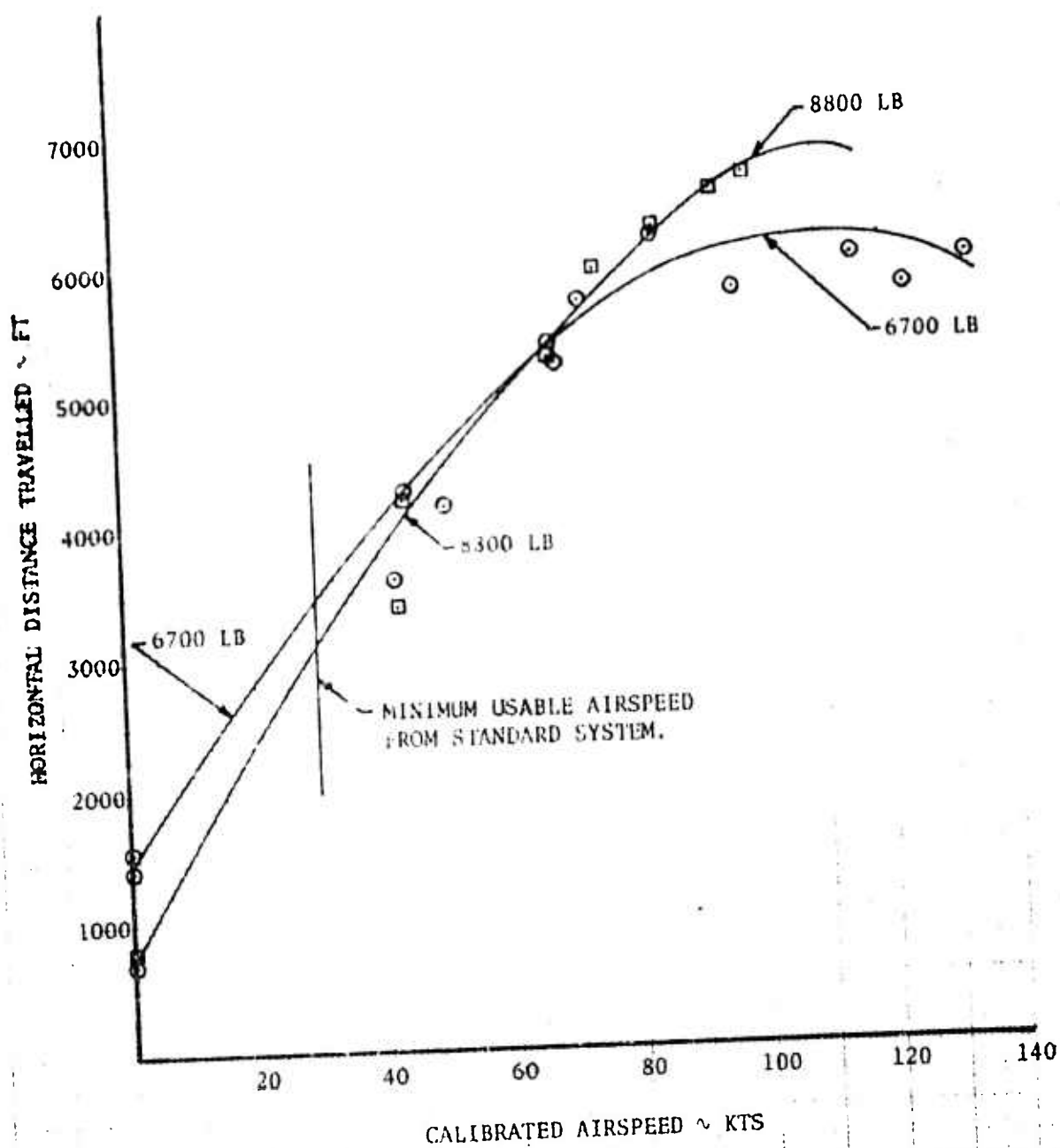


FIGURE 14
HORIZONTAL GLIDE DISTANCE VARIATION WITH ROTOR SPEED
UH-1C USA S/N 63-8684

AVG GROSS WT = 8800 LBS
AVG DENSITY ALT = 6000 FT
VERTICAL DESCENT = 1500 FT

SYM	TRUE AIRSPEED KTS
○	66
□	91
⊙	FROM FIG 11 @ 66
⊠	FROM FIG 11 @ 91

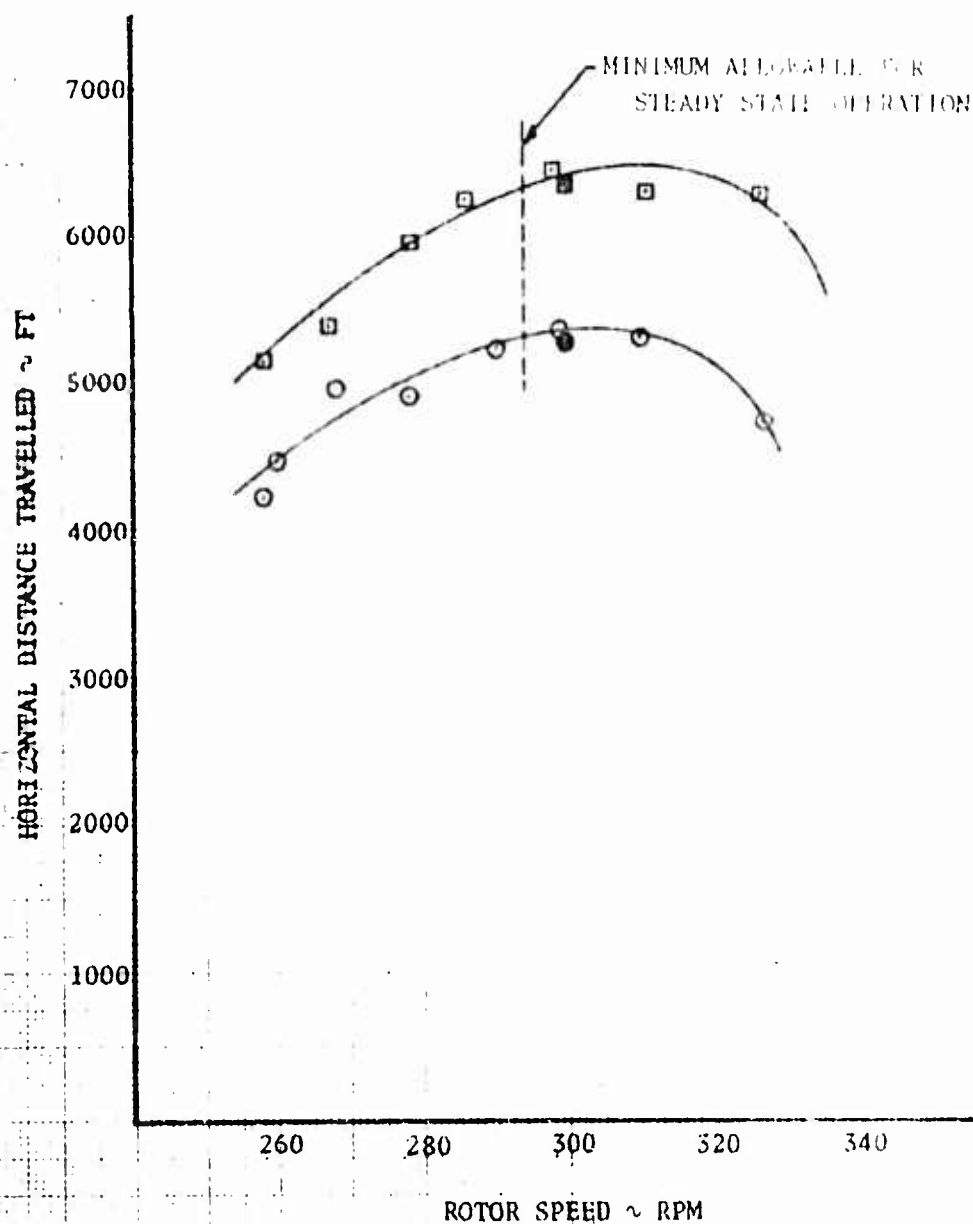
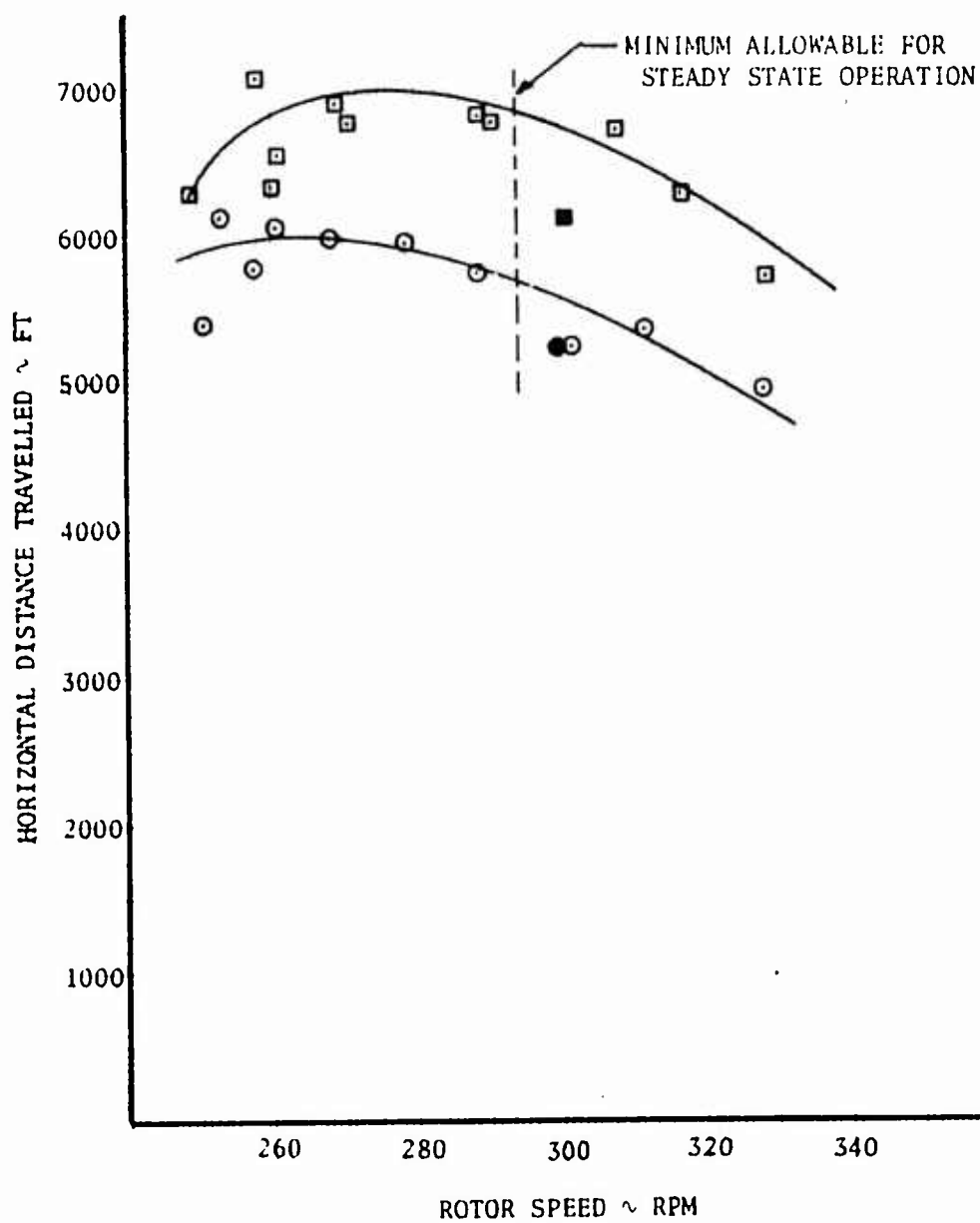


FIGURE 13
HORIZONTAL GLIDE DISTANCE VARIATION WITH ROTOR SPEED
UH-1C USA S/N 63-8684

AVG GROSS WT = 6700 LBS
AVG DENSITY ALT = 6000 FT
VERTICAL DESCENT = 1500 FT

SYM TRUE AIRSPEED ~ KTS

- 66
- 91
- FROM FIG 11 @ 66
- FROM FIG 11 @ 91



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13. ABSTRACT		
<p>A limited investigation was conducted by the US Army Aviation Systems Test Activity (USAASTA) at Edwards Air Force Base, California, to define the effects of various airspeeds, rotor speeds, engine rigging and gross weights on a UH-1C helicopter during autorotation. This investigation was prompted by a previous qualitative study of autorotational procedures (April 1968) and was requested by the Directorate of Rotary Wing Training, US Army Aviation School, Fort Rucker, Alabama. The latest investigation included 8 hours of productive flight testing between 6 and 14 October 1969, as well as a review of data obtained from earlier flight testing: the UH-1C Height-Velocity Study. Results of the investigation confirmed previous qualitative conclusions: that the use of low rotor speed to obtain maximum glide distance can be hazardous, especially at high gross weight conditions; and that current autorotation rate of descent information in operator's manuals is insufficient for the operator's use. The investigation further revealed that with a normal engine rigging, there is a measurable amount of engine output torque at low rotor speeds (310 rpm and below) during practice autorotations. This situation, encountered in a training environment, could produce a false sense of security in an individual faced with an actual emergency. Although the operational pilot cannot duplicate controlled test conditions, he should understand normal performance limits and the consequences of exceeding those limits. This report furnishes UH-1C autorotational data not currently available to the operator which should be incorporated into the appropriate manuals.</p>		

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